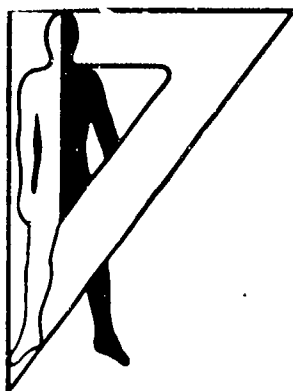


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Technical Memorandum 24-87

A COMPARISON OF KEYBOARD DESIGNS FOR COCKPIT APPLICATIONS

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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) This study was designed to compare three keyboard layouts and two feedback display locations under two simulated flight conditions. The dependent variables were data entry time, data entry errors, and the degree of interference with flight performance. Twenty-four helicopter pilots served as subjects. A mixed design was used with repeated measures on flying task and feedback display location, and with independent observations on keyboard type. The keyboard layouts included the Doppler arrangement, a telephone layout with two letters per key, and a full keyboard with the alpha and numeric keys separate; the feedback display locations were on the keyboard and on the panel in front of the pilot. One flight condition simulated low-level flight with obstacles; the other simulated straight and level instrument flight rules (IFR). The keyboard was always operated with a gloved left hand. The task was to enter navigational coordinate sets when prompted. The results showed the Doppler arrangement to be superior in response time and input time. There were significantly fewer errors when the feedback display was located on the panel.					
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A COMPARISON OF KEYBOARD DESIGNS FOR COCKPIT APPLICATIONS

INTRODUCTION

In advanced cockpits, keyboards have replaced rotary switches and thumbwheels used for entering information that control communication and navigation functions. Communication management tasks involve the selection and modification of radio frequencies for transmitting and receiving information in flight; navigation management tasks require the identification of routes and navigational coordinate sets. Both of these tasks are performed while the pilot is flying the aircraft. As a result, the pilot must divert his attention from the primary flying tasks to enter the needed information. An important research issue is how to design the keyboard to minimize the pilot's time away from controlling the aircraft.

There are several keyboards currently being manufactured for cockpit use. A brief review of the advertising indicates a wide variety of keyboard configurations and feedback display locations and suggests a lack of human factors guidelines in the design process. The most critical issue in keyboard design for aircraft cockpits is how to ensure fast and accurate keying while overcoming the interferences resulting from turbulence, vibration, gloved-hand operation, and pilot time-sharing with a primary task. Several studies have been conducted on keyboard design for cockpit applications. Specific areas include keyboard location (Reising, Calhoun, Bateman, & Herron, 1977), keyboard and keypad layout (Butterbaugh & Rockwell, 1982; Koppa, 1985), keyboard ergonomics (Alden, Daniels, & Kanarick, 1972; Hansen, 1983), and keyboard operation with gloved hand (Taylor & Berman, 1982; 1983). Some of these studies have produced research results that can be used as design standards; others have narrowed the ranges on specific variables but have not provided optimum solutions.

The two areas needing additional research are keyboard layout and the type and location of feedback verifying the data input. Butterbaugh and Rockwell (1982) evaluated four keying logics involving the entry of alphanumeric characters. The logics were based on current keyboard designs used for communication and navigational functions in aircraft. The subjects' task was to key in clusters of alphanumerics representing flight navigational coordinate sets. The results showed that the fewest keying errors were made when the alpha keys were separated from the numeric keys. A different keyboard was recommended when space is limited. One concern with the Butterbaugh and Rockwell study is that scientists were used as subjects. Since pilots are the ultimate users, it is their performance on the keyboards that should be measured. Additionally, each keyboard should be evaluated for its degree of interference with the pilot's primary task of flying the aircraft. A final concern is the location of the feedback device and the impact of this location on keying accuracy and flying accuracy. Little work has been done in this area.

OBJECTIVE

The present study was designed to compare three keyboard layouts and two feedback display locations under two simulated flight conditions. The pilot's task was to fly a helicopter simulator in either a low-level flight or a straight and level instrument flight rules (IFR) flight condition and enter navigational coordinate sets when prompted. The objective was to determine which keyboard and visual feedback configuration would result in the fastest data entry, the fewest errors, and the least interference with flying performance.

METHODOLOGY

Participants

Twenty-one U.S. Army National Guard and three U.S. Army helicopter pilots served as subjects. The National Guard pilots were assigned to various locations in Maryland; the Army pilots were from Aberdeen Proving Ground, Maryland. Table 1 provides an overview of the subjects' backgrounds and experiences. Some specific characteristics include

- ages ranging from 25 to 50 with a mean age of 36; all subjects are male.
- years of experience ranging from 1 to 21 years with a mean of 11.
- total flight hours in a helicopter ranging from 300 to 11,500 with a mean of 2,300.
- flight hours per month ranging from 0 to 50 with a mean of 17.
- sixty-seven (67) percent of the subjects indicating on the background questionnaire that they had at least some experience with data entry keyboards.
- two of the subjects having experience with the fixed-base helicopter simulator at the Human Engineering Laboratory at Aberdeen Proving Ground.

Apparatus

The equipment used in this study included (a) a helicopter simulator; (b) flight displays and controls; (c) a graphics simulation for a low-level flight; (d) a VAX®11/780, a VAX®11/750, and a PDP11®-34 computer and terminal; (e) three experimental keyboards; (f) a movable plasma display for presenting feedback; and (g) the DECTalk® voice synthesizer default voice with a typical male voice.

Table 1

Subjects' Background

Subjects	Age	Years of experience	Total flight hours	Flight hours per month	Data entry experience
S1	38	7	1,200	10	Some
S2	38	15	2,500	15	None
S3	34	5	1,000	8	Some
S4	36	12	2,600	30	Some
S5	25	2	400	30	Some
S6	28	3	700	10	Some
S7	40	20	350	10	Some
S8	41	10	1,750	10	Some
S9	22	1	300	8	Some
S10	38	18	8,200	25	A lot
S11	39	14	1,500	8	Some
S12	28	6	900	10	None
S13	27	2	410	12	None
S14	39	18	3,000	10	None
S15	36	16	2,000	0	Some
S16	40	19	11,500	50	None
S17	39	11	3,000	40	Some
S18	40	17	3,500	10	Some
S19	51	21	3,000	42	None
S20	37	11	2,500	10	None
S21	27	1	300	10	Some
S22	38	4	1,500	40	Some
S23	40	18	1,500	6	None
S24	50	17	1,800	8	Some

Flight Simulator and Graphics Display

The Cockpit Research, Experimentation, and Workload (CREW) Simulator consists of a cockpit cab with advanced controls and displays and an out-the-window scene produced by computer-generated imagery (CGI). The CGI system models a 5-square mile gaming area of trees, hills, rivers, roads, and buildings. A 40-degree by 40-degree field of view is projected on a 6-foot by 6-foot screen to the front of the cockpit cab. The CGI and the cockpit controls and displays are driven by a VAX®11/750 computer and a VAX®11/780 computer, respectively. The flight display presented information on heading, altitude, speed, torque, pitch, and yaw.

Keyboards and Feedback Display

Three keyboards were tested. One of these was laid out according to the recommendations of Butterbaugh and Rockwell (1982). This configuration is shown in Figure 1 along with the plasma display used for presenting feedback. The second design, similar to the keyboard layout, is the Doppler Navigation Set AN/ASN-128 (see Figure 2). In this design, three alpha characters are included on each numeric key. When an alpha character is required, the operator must press the appropriate alpha key (left, center, or right) to indicate which position on the key is desired; then the letter key is pressed. The third configuration has only two letters on each numeric key and two alpha position keys, left and right (see Figure 3).

The arrow keys on the keyboards were used to move the cursor backward or forward to the desired position for making a correction. Corrections were made by positioning the cursor and pressing the appropriate letter or number. The ENTER key was pressed to enter the string of numbers; the CLEAR ENTRY key was used to clear the entire string of numbers. It was not necessary for the cursor to be placed at the end of the string to enter or clear the entry.

Two visual feedback conditions were used. In one condition, the keyed data appeared on a display on the panel in front of the pilot as it was entered. In the second condition, the feedback display was located with the keyboard. In this condition, the pilot did not need to look away from the keyboard to obtain feedback. The keyboards were located next to the pilot's left hand. Figure 4 shows the feedback display and keyboard located together; Figure 5 shows the configuration with the feedback display on the panel.

DECTalk®Voice Synthesizer

The voice synthesizer provides seven different voices. The DECTalk® default voice, a typical male voice, was used during the study.

Procedure

Briefing

Each subject was individually briefed, trained, and tested. During the briefing, the purpose of the experiment and the training and testing procedures were described. Also, each subject read and signed a volunteer consent form

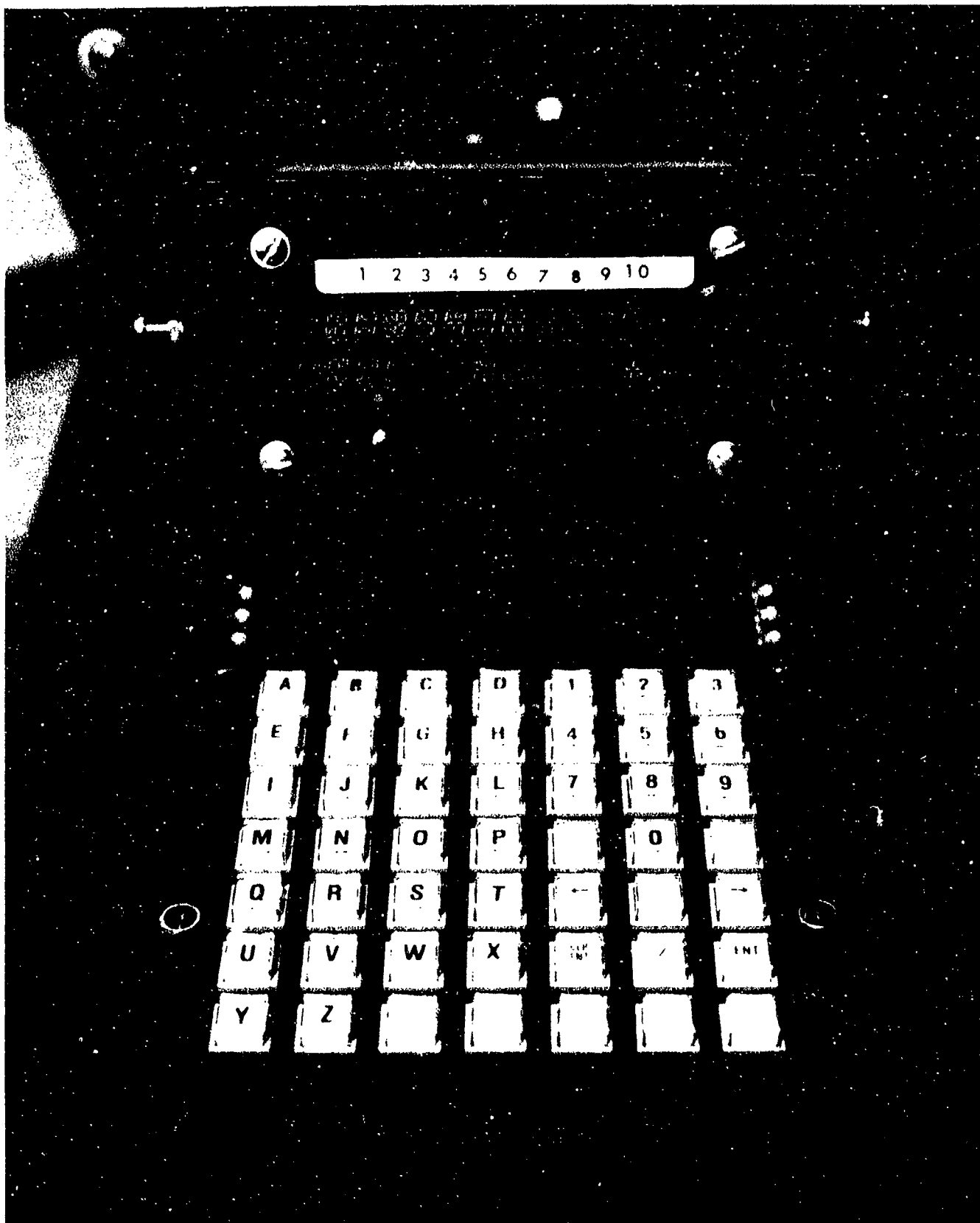


Figure 1. Full alphabetic keyboard.

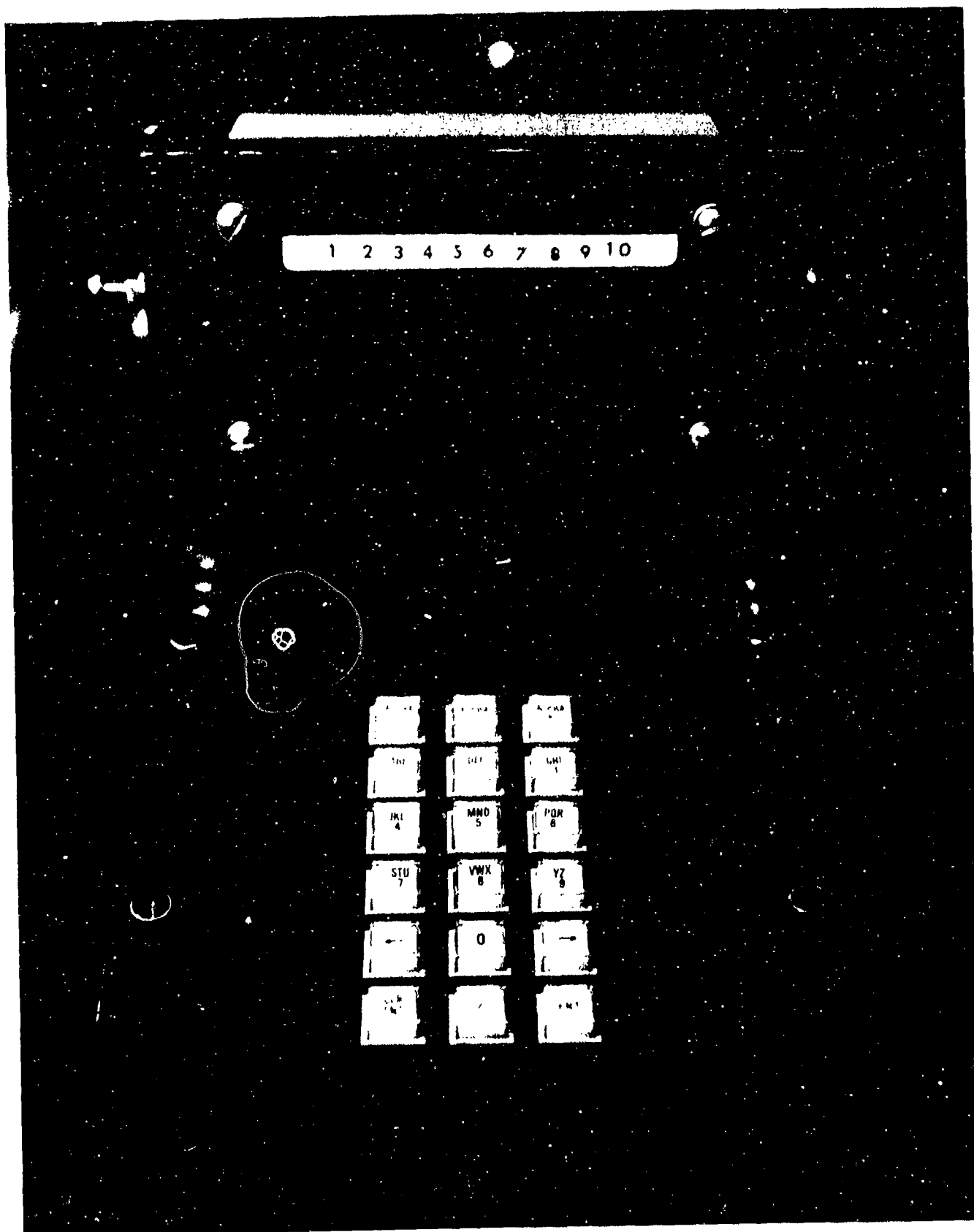


Figure 2. Doppler navigation set keyboard.

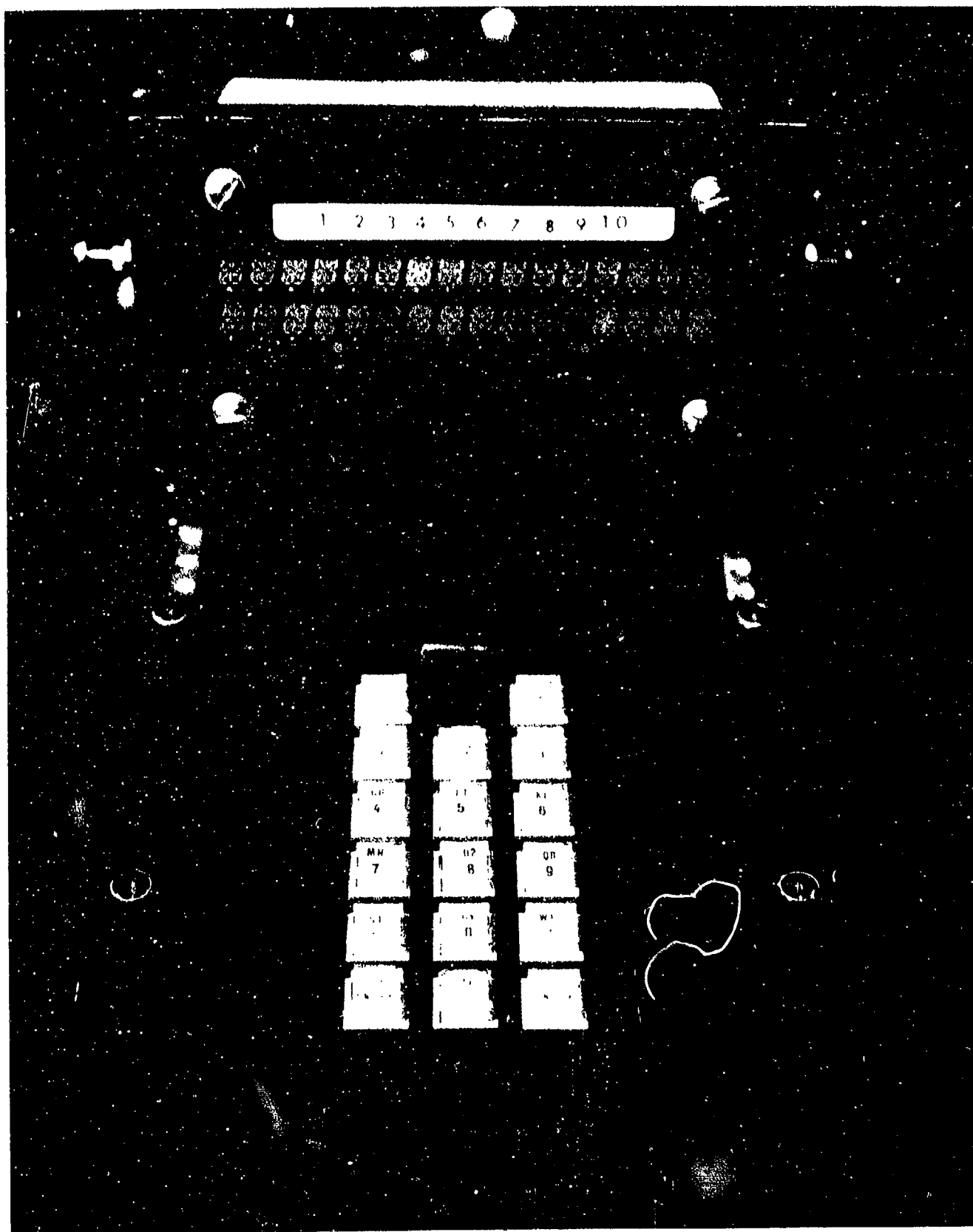


Figure 3. Two-letters-per-key keyboard.



Figure 4. Feedback at keyboard position.

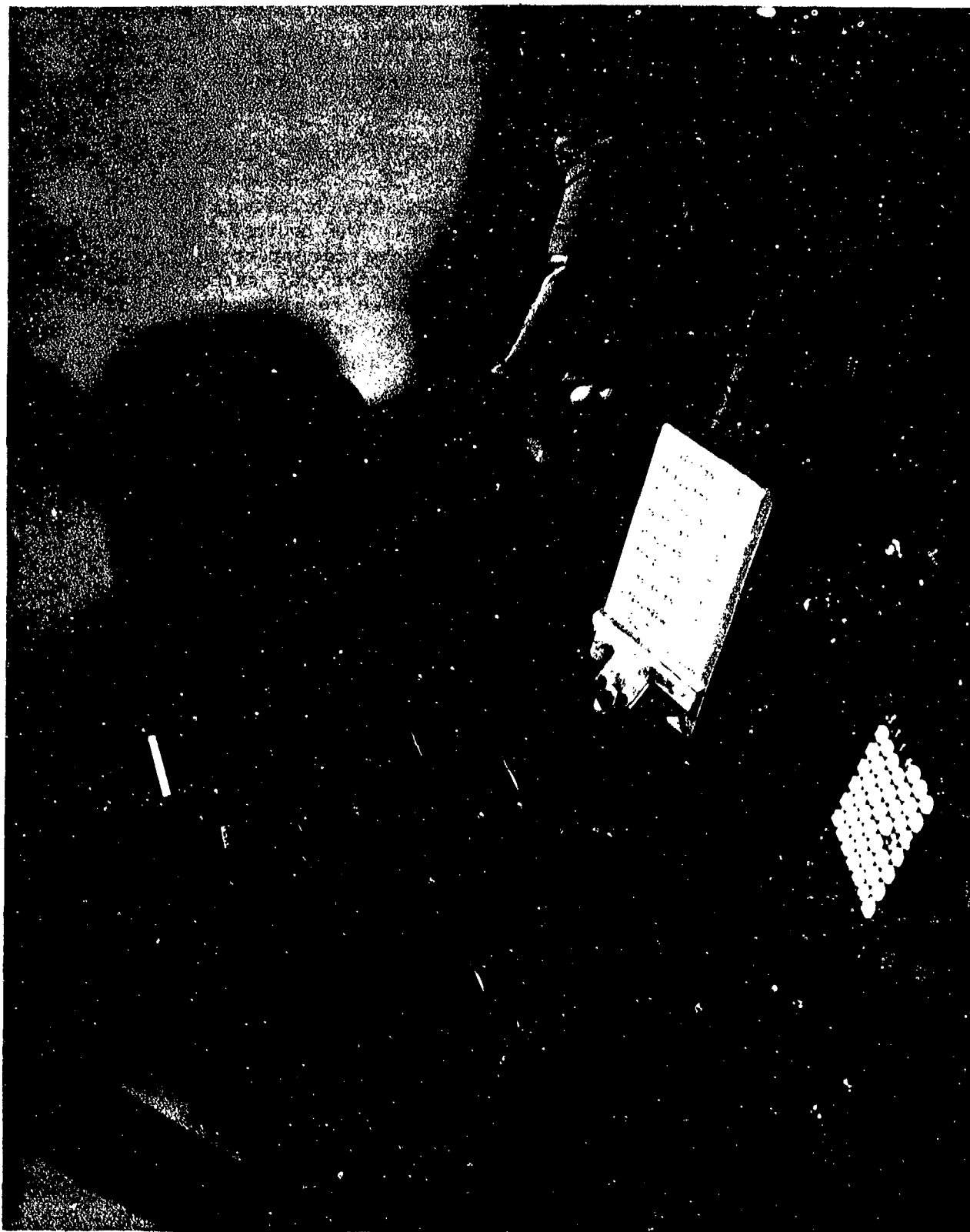


Figure 5. Feedback at panel position.

(Appendix A) and completed the background questionnaire (Appendix B). Subjects were informed that the training would require about 2 hours and the testing another 2 hours. They were then shown the keyboard they would be using for data entry and told about the various flight conditions included in the study. Each subject used only one of the three keyboards but was exposed to both feedback display locations and both flight conditions.

Training

1. Simulator. Immediately following the briefing, the subject was given time to become familiar with the simulator. The controls and displays were explained, and a sample flight course was provided for practice runs. For the low-level condition, the course was generated by the CGI system. For the IFR condition, the subject was told to maintain a given heading, speed, and altitude by using the flight display. Each subject had two practice flights prior to the actual testing on each flight condition.

2. Keyboards. Since each subject was tested on only one of the three keyboards, training was only provided on the keyboard that was used during testing. The procedures for data entry and error correction were explained and demonstrated. The subject was then given a sample of eight navigational coordinate sets to enter in a practice session. Proficiency was defined as the ability to enter five navigational coordinate sets without error. The order of training and testing was as follows:

1. Train on the simulator for both flight conditions.
2. Train on the keyboard.
3. Practice data entry and flying for the first set of test flight conditions.
4. Perform the test.
5. Practice data entry and flying for the second set of test flight conditions.
6. Perform the test.

Testing

Two types of tasks were used — data entry tasks and flying tasks. The data entry task consisted of entering navigational coordinate sets. Specific data to be entered were selected from lists of actual Universal Transverse Mercator (UTM) coordinate sets. (Appendix C shows the navigational coordinate sets used for each condition.) Performance measures for the data entry task were accuracy, speed, and the number of errors recognized and corrected. Flying tasks included one low-level flight condition that involved following a river and avoiding obstacles and one IFR flight condition that involved maintenance of appropriate heading, speed, and altitude. Measurements were taken of deviations from the prescribed course, altitude, and speed. Data entry and flying tasks were performed simultaneously. This determined the degree of interference between the two tasks under the three keyboard configurations and the two feedback conditions.

For the low-level flight, the subjects were instructed to follow the river, to fly as fast as possible, and to stay at tree-top level. The conditions for the IFR flight were (a) heading - 240 degrees, (b) speed - 30 knots, and (c) altitude - 100 feet.

During training and testing, the subject wore flight gloves and an aviator's helmet. A lighted kneeboard containing lists of navigational coordinate sets was attached to the subject's left knee.

Experimental Design

Table 2 shows the experimental design. Three groups of eight subjects were used; each group performed the data entry task on one of the keyboards for both flight conditions and for both feedback conditions. Thus, each subject performed four trials. A trial was about 30 minutes long. The order of testing for flight conditions and the feedback display placement within the flight condition was counterbalanced. This is a mixed design with repeated measures on flying task and feedback display location and with independent observations on keyboard type. For each analysis, the data were summed across the eight navigational coordinate sets for each subject and each flight display condition. The CGI system was used to generate the low-level flight segment. While the subject was controlling the simulator for each flight condition, he was asked to enter eight navigational coordinate sets. The DECTalk® voice synthesizer was used to prompt the subject for the data entry task. Time between data entry varied from 45 seconds to 2-1/2 minutes. For the low-level flight condition, the navigational coordinate sets were programmed at points in the course; thus the time between waypoint prompts was determined by the subject's airspeed.

Table 2

Experimental Design

	<u>IFR flight</u>		<u>Low-level flight</u>	
	Feedback on panel	Feedback on keyboard	Feedback on panel	Feedback on keyboard
Keyboard 1				
S1				
S2				
S3				
S4				
S5				
S6				
S7				
S8				
Keyboard 2				
S9				
S10				
S11				
S12				
S13				
S14				
S15				
S16				
Keyboard 3				
S17				
S18				
S19				
S20				
S21				
S22				
S23				
S24				

Data Collection

All performance data were collected by computer. Specific measures for data entry included response time, input time, and errors. They are defined as follows:

1. Response time is the time between the prompt from DECtalk® and the first keystroke.
2. Input time is the time between the first keystroke and the last keystroke.
3. Three types of input errors were collected -- uncorrected errors, corrected errors, and incomplete input errors.

Flight performance data were sampled four times per second, averaged, and printed once per second by the computer. In the IFR flight, heading, airspeed, and altitude were measured. For the low-level flight, the measures included deviations from the flight path (center of riverbed), airspeed, and altitude. Deviations from the set flight path were measured in x- and y-coordinates related to the computer-generated imagery system. These deviations were measured as root-mean-square (RMS) error from the set flight path. Flight performance during the time the subject was entering a coordinate was compared with flight performance as a sole task. This was accomplished by measuring the subject's flight performance for the same length of time prior to data entry and during data entry.

Following testing, each subject completed a subjective questionnaire indicating his preferences for display location and describing the positive and negative aspects of the keyboard layout used. The questionnaire is shown in Appendix D.

RESULTS

Objective Data

A 3 x 2 x 2 analysis of variance was done for each data entry dependent variable and for each flight parameter (see Appendix E for specific statistical tables). Data entry variables included total errors, input time, and response time; flight parameters included the difference between prescribed and actual heading, airspeed, and altitude for IFR flight, both before and during data entry, and the deviations from the prescribed course for low-level flight, both before and during data entry. The F-Max Test for homogeneity of variance was run for each dependent variable. Since the assumption of homogeneity was violated for errors, and for three IFR flight parameters, log transformations were performed. A log transformation was also calculated for course deviations in the low-level flight condition. The acceptable alpha level for all tests in the study is $p < .05$.

Data Entry Total Errors

The analysis of variance for total errors showed one significant difference -- display location, $F(1, 21) = 11.02$, $p < .01$; there were no differences between the keyboards. The means for display location are presented in Table 3.

Table 3
Display Location: Total Errors (Means)

Keyboard type	Display location	
	Panel	Keyboard
Full	4.6	4.5
Doppler	3.6	5.4
Two letters per key	3.6	6.1
Total	3.9	5.3

Table 3 indicates that fewer errors were committed when the feedback display was located on the panel than when it was located on the keyboard.

Although no significant differences in total errors were found for the keyboard type, it is of interest to show the distribution of errors by flight condition. Table 4 presents the means for this interaction. Use of the full keyboard for data entry resulted in the fewest errors for low-level flight and for the greatest number of errors during the IFR flight. Of the total number of errors, 68 percent were uncorrected.

Table 4
Keyboard Type by Flight Condition: Total Errors (Means)

Keyboard type	Flight condition	
	IFR	Low-level
Full	5.9	3.2
Doppler	4.4	4.6
Two letters per key	4.3	5.4
Total	4.9	4.4

Data Entry Response Time

Response time is the time between the DECTalk® navigational coordinate sets prompt and the first data entry keystroke. The analysis of variance for this dependent variable showed a significant difference between keyboard type, $F(2, 21) = 4.4$, $p < .05$, and between flight conditions, $F(1, 21) = 16.7$, $p < .0005$; no differences were found between the two display locations. The mean response times for the three keyboard types were

Full - 10.1 seconds
Doppler - 6.9 seconds
Two letters per key - 10.9 seconds

Scheffé's test indicated that the response time for the Doppler keyboard layout is significantly faster than for the two-letters-per-key layout ($p < .05$). The mean response times for the flight conditions were 7.3 seconds for the low-level flight and 11.2 seconds for the IFR flight.

Data Entry Input Time

Input time is the time between the first keystroke and pressing the ENTER key. The analysis for this variable showed significant differences between keyboard type, $F(2, 21) = 5.3$, $p < .05$, and between flight conditions, $F(1, 21) = 6.5$, $p < .05$. The mean for each keyboard type was

Full - 24.3 seconds
Doppler - 17.6 seconds
Two letters per key - 27.2 seconds

As with response time, the Doppler layout is significantly faster for data entry (Scheffé's test) than the two-letters-per-key layout ($p < .05$). The mean for low-level flight was 24.4 seconds, and for IFR flight, 21.6 seconds. This result is opposite from the result for response time. If the mean response time and the mean input time are added together, the resulting means would be

Low-level - 31.7 seconds
IFR - 32.8 seconds

Flight Parameters

A separate analysis was performed for each flight condition and each flight parameter. The primary purpose of these analyses was to determine whether the keyboard layouts or the display locations interfered with controlling the flight simulator. The dependent variables were heading, airspeed, and altitude for the IFR flight, and flight path deviation for the low-level flight. Mean performance on each variable was calculated for the time during data entry and for the same period prior to data entry. Comparisons were then made between each parameter before and during data entry for each keyboard and for each display location. The results showed no differences between keyboard types or display locations; the only significant finding was that control of the aircraft was generally better prior to data entry for IFR flight than during data entry for IFR flight (heading, $F[1, 20] = 33.3$, $p < .0001$; airspeed, $F[1, 20] = 8.4$, $p < .01$). The means for each parameter are shown in Table 5.

Table 5
Deviations From Specified Flight Path Values

Flight path value	Before data entry	During data entry
IFR		
Altitude (feet)	5.85	2.32
Airspeed (knots)	.49	2.00
Heading (degrees)	.20	9.80
Low-level		
Flight path deviation- RMS error (feet)	64.50	72.9

Subjective Data

Following testing, each subject completed a questionnaire in which they indicated their preference for the display location for low-level and IFR flights. The results are shown in Tables 6 and 7.

The feedback display location preferences for both data entry and maintaining flight performance were mixed; approximately one-half of the subjects preferred the panel, and the other half preferred the keyboard. The one exception is the slightly stronger preference for keyboard location when the full keyboard was used.

Table 6
Preferred Display Location for Keying

Keyboard type	<u>Low-level</u>		<u>IFR</u>	
	Panel	Keyboard	Panel	Keyboard
Full	3	5	2	6
Doppler	4	4	5	3
Two letters per key	5	3	4	4
Total	12	12	11	13

Table 7

Preferred Display Location for Maintenance of Flight Performance

Keyboard type	<u>Low-level</u>		<u>IFR</u>	
	Panel	Keyboard	Panel	Keyboard
Full	4	4	2	6
Doppler	4	4	6	2
Two letters per key	4	4	6	2
Total	12	12	14	10

The following are some of the favorable comments made when the feedback display was located on the panel:

- It was easier to check entries because the display was in the normal scan pattern for all instruments.

- In the low-level mode, it was easier to make the transition from the instruments to the terrain. It allowed the pilot to spend more time looking outside the cockpit.

- Less head movement was required, and there was less possibility for spatial disorientation.

Comments favoring the keyboard location of the feedback display included

- It was easier to check entries as they were being made.

- Less eye movement was required from the keyboard to the display. It was necessary to look at the keyboard anyway.

In addition to evaluating display location, subjects were asked to comment on keyboard layout. Table 8 shows the assessment of each keyboard for ease of use. Seventeen of the 24 subjects (71 percent) felt comfortable with the keyboard that they used for data entry in the experiment.

Table 8

Subjective Keyboard Evaluation

Keyboard type	Easy to use	Hard to use
Full	6	2
Doppler	5	3
Two letters per key	6	2
Total	17	7

The most frequent suggestions about all the keyboards were

- Separate the alpha mode keys on the Doppler and the two-letters-per-key keyboards from the alphanumeric keys.
- Provide a home key; raise the middle row, or put a ridge on the center key. This will allow accurate hand placement without looking at the keyboard.
- Segregate the ENTER key or increase its size.
- Provide different feedback for the ENTER key and the CLEAR ENTRY key. In the current study, the numbers on the feedback display disappeared when either key was depressed.
- Provide a heads-up display for the keyboard. This would limit body and head movement, thus minimizing the possible occurrence of dizziness.

DISCUSSION

This study had two objectives: first, to compare three keyboard layouts and two feedback display locations for accuracy and efficiency of data entry while flying a helicopter; and second, to compare the layouts and feedback locations in terms of interference with controlling a helicopter. To accomplish the first objective, data entry times and error data were collected on 24 helicopter pilots as they entered navigational coordinate sets under four different conditions of flight and feedback display location. These conditions were

Low-level flight with feedback display located on panel

Low-level flight with feedback display located on keyboard

IFR flight with feedback display located on panel

IFR flight with feedback display located on keyboard

As described in the experimental design, subjects were assigned in groups of eight to each of the three keyboards.

The results of the analysis of time and error data suggest that the Doppler keyboard arrangement is significantly faster than the two-letters-per-key keyboard layout for both response time and input time. The panel location of the feedback display resulted in significantly fewer errors than the keyboard location for the Doppler and two-letters-per-key keyboards. Although not a significant difference, the mean times for the Doppler were faster than those for the full keyboard. The demonstrated superiority of the Doppler arrangement in terms of response and input time may be attributed to several factors. First, because the Doppler is installed in several helicopters, many pilots in the study had some familiarity with this layout. Using an unfamiliar layout, even after training, could lead to slower data entry particularly while also performing the tasks required to fly the simulator. It should be noted that flying the simulator was also a new task, and it was a difficult task for many of the pilots to master because the control characteristics were slightly different from those of a helicopter. Second, on the Doppler keyboard, the alpha keys used for all the navigational coordinate sets were closer together; the key containing NM was the home key (center key in second row) rather than the key on the far left in the third row (as on the two-letters-per-key keyboard). The alpha characters used in the navigational coordinate sets were NA, NB, MA, and MB. Assuming that the natural position for the hand is to rest on and return to center row, the N or M would be directly under the middle finger on the Doppler keyboard. The alpha characters used in this study were chosen to represent operational situations; if other combinations of letters had been used the results might have been different.

A review of the error results for feedback display location shows that the best location is the panel, for both the Doppler and the two-letters-per-key keyboard layouts; for the full keyboard, the mean errors for the two feedback locations were the same. One explanation for this result is that the navigational coordinate set data on the display was easier to cross-check with the list on the kneeboard when the display was directly in front of the pilot; he did not have to look down and away from the outside or the other instruments to make the necessary checks.

The data analysis comparing the keyboards and feedback display locations in terms of their degree of interference with simulator control showed no differences among the different designs. The only difference was that control was better before data entry than during data entry in the IFR flight condition. The measures reflecting these findings were (a) course deviations before and during data entry and (b) airspeed deviations before and during data entry.

CONCLUSIONS

Several conclusions can be drawn from the present study. Data entry using all three keyboard layouts and both feedback display locations interfered with flight performance. The Doppler layout is superior to the other two layouts, for both response time and input time; the Doppler is also more consistent in mean errors across flight conditions (see Table 4). Locating the feedback display on the panel rather than next to the keyboard resulted in significantly fewer data entry errors.

RECOMMENDATIONS

Based on the results of this study it is recommended that the Doppler layout be used for navigational data entry in helicopters and that the feedback display be located on the panel in front of the pilot. It is suggested, however, that additional research be conducted on the following issues:

- Further segregating the function keys from the alphanumeric keys
- Differentiating the home row or home key
- Testing the keyboard on the panel in front of the pilot or providing a heads-up display
- Testing a wider combination of alpha characters

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APPENDIX A
VOLUNTEER CONSENT FORMS

VOLUNTEER AGREEMENT

You are assisting in an investigation comparing different keyboard layouts and feedback positions for entering navigational coordinates.

This investigation is being conducted in the Human Engineering Laboratory (HEL) flight simulation facility, Building 459, to determine if there are any differences in the speed and accuracy of the different keyboard layouts and feedback positioning, as well as if flight performance is affected by data entry. The research will contribute to efforts to design future cockpits so that pilot performance is enhanced and workload is reduced.

First, you will be familiarized with the flight simulator to be used. Two different flight scenarios will be flown. Practice flights will be provided for each scenario, in addition to practice entering coordinates on the keyboard to be tested.

Upon completion of the practice sessions, you will enter navigational coordinates using the keyboard while controlling the flight simulator under four conditions:

- (1) Data entry during IFR flight with feedback located with the keyboard.
- (2) Data entry during IFR flight with feedback located on the console.
- (3) Data entry during low-level flight with feedback located with the keyboard.
- (4) Data entry during low-level flight with feedback located on the console.

You will then be asked to complete a brief questionnaire and to provide your opinions concerning the different test conditions.

You will not be subjected to any known risks or discomforts.

Your participation in this investigation will require approximately 4 hours.

Performance data and questionnaire information will be coded so that results of your participation are confidential.

Your participation in the study is voluntary, and you may stop participating at any time without penalty. However, due to the small number of aviators available, a decision to withdraw from participation will impede the successful completion of this research.

Participant's Initials

VOLUNTEER AGREEMENT

I, _____, having full capacity to consent, do hereby volunteer to participate in a research study entitled "A Comparison of Keyboard Designs for Cockpit Applications." This research is being conducted by

Ann Mavor
Essex Corporation
Alexandria, VA 22314

Kathleen Christ
Aviation & Air Defense Division
Human Engineering Laboratory
U.S. Army Laboratory Command
Aberdeen Proving Ground, MD 21005-5001

The implications of my voluntary participation; the nature, duration, and purpose; the methods and means by which the study will be conducted; and the inconvenience or hazards that may reasonably be expected have been explained to me by _____ and are set forth on pages 1 and 2 of this agreement, which I have initialed. I have been given an opportunity to ask questions concerning this investigational study, and any such questions have been answered to my full and complete satisfaction.

Signature date

Witness' Signature date

APPENDIX B
BACKGROUND QUESTIONNAIRE

BACKGROUND QUESTIONNAIRE

NAME: _____

AGE: _____

GRADE/RANK: _____

TOTAL NO. OF YEARS AS A RATED AVIATOR: _____

TOTAL HOURS IN ROTARY-WING: _____

WHICH HELICOPTERS ARE YOU RATED IN? _____

TOTAL HOURS IN FIXED-WING: _____

AVERAGE NO. OF HOURS YOU ARE CURRENTLY FLYING PER MONTH: _____

DO YOU HAVE ANY EXPERIENCE USING A DATA ENTRY KEYBOARD?

_____ NONE

_____ SOME

_____ A LOT

WHEN WAS THE LAST TIME YOU USED A DATA ENTRY KEYBOARD? _____

APPENDIX C
UTM NAVIGATIONAL COORDINATE SETS

UTM NAVIGATIONAL COORDINATE SETS

LOW-LEVEL

NA40789517
 NA58139788
 NB73940770
 NB88432811
 MB87560673
 NA08838985
 NB31520135
 NB47443727

LOW-LEVEL

MB84903227
 MB78822905
 MA84509011
 NB20370295
 NB35090738
 NB52583877
 NB73484430
 NA71699492

IFR

MB84793615
 NA14879877
 NB41731976
 NB60879877
 NB85022498
 NB73121346
 NA61559166
 NA21439335

IFR

NA27509475
 NA66349005
 NB82192130
 NB91663910
 NB43452728
 MB82102503
 MB84451223
 NB44023345

APPENDIX D
SUBJECTIVE QUESTIONNAIRE

SUBJECTIVE QUESTIONNAIRE

FOR LOW-LEVEL FLIGHTS

1. Which feedback display location did you prefer for performing the data entry task?

_____ NEXT TO KEYBOARD _____ ON THE PANEL _____ NO DIFFERENCE

Briefly explain your reasons. _____

2. Which feedback display location interfered the least with the flying activities?

_____ NEXT TO KEYBOARD _____ ON THE PANEL _____ NO DIFFERENCE

Briefly explain your reasons. _____

FOR IFR FLIGHTS

3. Which feedback display location did you prefer for performing the data entry task?

_____ NEXT TO KEYBOARD _____ ON THE PANEL _____ NO DIFFERENCE

Briefly explain your reasons. _____

4. Which feedback display location interfered the least with the flying activities?

_____ NEXT TO KEYBOARD _____ ON THE PANEL _____ NO DIFFERENCE

Briefly explain your reasons. _____

FOR BOTH FLIGHTS

5. Was the layout of the keyboard easy to use?

_____ YES

_____ NO

If no, how would you change the layout? _____

APPENDIX E
STATISTICAL TABLES

Table E-1

Data Entry Total Errors (log)
Means Summary Table

Keyboard type	Flight condition	Display location	N	Mean	Standard Deviation
Doppler	Low-level	Keyboard	6	1.497	1.028
Doppler	Low-level	Keyboard	6	1.212	0.638
Doppler	IFR	Panel	6	1.650	0.477
Doppler	IFR	Panel	6	1.007	0.702
Two letters	Low-level	Keyboard	5	2.144	0.358
Two letters	Low-level	Keyboard	5	1.383	0.633
Two letters	IFR	Panel	5	1.888	0.387
Two letters	IFR	Panel	5	0.921	0.846
Full	Low-level	Keyboard	7	0.979	0.741
Full	Low-level	Keyboard	7	1.080	0.891
Full	IFR	Panel	7	1.776	0.369
Full	IFR	Panel	7	1.526	0.915

Table E-2

Data Entry Total Errors (log)
Analysis of Variance Summary Table

Source	df	SS	MS	F	p
Between subjects	17	12.9404			
Keyboard type (K)	2	0.8554	0.4277	0.531	0.6017
Subject with Groups (SwGps)	15	12.0850	0.8057		
Within subjects	54	27.1796			
Flight condition (F)	1	0.3194	0.3194	0.612	0.4462
K x F	2	3.0322	1.5161	2.904	0.0853
F x SwGps	15	7.8314	0.5221		
Display location (D)	1	3.2315	3.2315	11.024	0.0047*
K x D	2	1.8350	0.9175	3.130	0.0726
D x SwGps	15	4.3968	0.2931		
F x D	1	0.4413	0.4413	1.090	0.3129
K x F x D	2	0.0198	0.0099	0.024	0.9760
F x D x SwGps	15	6.0722	0.4048		

* = significant result.

Table E-1

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Table E-2

Data Entry Total Errors (log)
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Keyboard type (K)	2	0.8554	0.4277	0.531	0.6017
Subject with Groups (SwGps)	15	12.0850	0.8057		
Within subjects	54	27.1796			
Flight condition (F)	1	0.3194	0.3194	0.612	0.4462
K x F	2	3.0322	1.5161	2.904	0.0853
F x SwGps	15	7.8314	0.5221		
Display location (D)	1	3.2315	3.2315	11.024	0.0047*
K x D	2	1.8350	0.9175	3.130	0.0726
D x SwGps	15	4.3968	0.2931		
F x D	1	0.4413	0.4413	1.090	0.3129
K x F x D	2	0.0198	0.0099	0.024	0.9760
F x D x SwGps	15	6.0722	0.4048		

* = significant result.

Table E-3

Data Entry Response Time (seconds)
Means Summary Table

Keyboard type	Flight condition	Display location	N	Mean	Standard Deviation
Doppler	Low-level	Keyboard	8	5.265	2.414
Doppler	Low-level	Keyboard	8	4.520	2.185
Doppler	IFR	Panel	8	8.422	3.505
Doppler	IFR	Panel	8	9.269	3.159
Two letters	Low-level	Keyboard	8	9.039	2.781
Two letters	Low-level	Keyboard	8	10.058	7.401
Two letters	IFR	Panel	8	13.878	8.273
Two letters	IFR	Panel	8	10.604	2.693
Full	Low-level	Keyboard	8	7.943	2.814
Full	Low-level	Keyboard	8	7.176	4.039
Full	IFR	Panel	8	11.094	3.377
Full	IFR	Panel	8	14.307	5.222

Table E-4

Data Entry Response Time (seconds)
Analysis of Variance Summary Table

Source	df	SS	MS	F	p
Between subjects	23	984.1054			
Keyboard type (K)	2	292.5700	146.2850	4.442	0.0244*
Subject with Groups (SwGps)	21	691.5350	32.9302		
Within subjects	72	1436.5316			
Flight condition (F)	1	370.4500	370.4500	16.861	0.0005*
K x F	2	23.9867	11.9934	0.546	0.5903
F x SwGps	21	461.3918	21.9710		
Display location (D)	1	0.0570	0.0570	0.005	0.9435
K x D	2	22.0893	11.0446	0.996	0.3907
D x SwGps	21	232.9546	11.0931		
F x D	1	1.0916	1.0916	0.091	0.7659
K x F x D	2	72.5085	36.2542	3.021	0.0698
F x D x SwGps	21	252.0024	12.0001		

* = significant result.

Table E-5

Data Entry Input Time (seconds)
Means Summary Table

Keyboard type	Flight condition	Display location	N	Mean	Standard Deviation
Doppler	Low-level	Keyboard	8	20.184	9.587
Doppler	Low-level	Keyboard	8	20.604	5.527
Doppler	IFR	Panel	8	13.770	2.325
Doppler	IFR	Panel	8	15.882	3.842
Two letters	Low-level	Keyboard	8	25.939	6.230
Two letters	Low-level	Keyboard	8	31.550	10.193
Two letters	IFR	Panel	8	25.595	10.220
Two letters	IFR	Panel	8	25.787	9.381
Full	Low-level	Keyboard	8	24.653	5.856
Full	Low-level	Keyboard	8	23.728	5.527
Full	IFR	Panel	8	22.652	8.211
Full	IFR	Panel	8	26.241	8.879

Table E-6

Data Entry Input Time (seconds)
Analysis of Variance Summary Table

Source	df	SS	MS	F	p
Between subjects	23	4615.4053			
Keyboard type (K)	2	1554.3025	777.1513	5.331	0.0133*
Subject with Groups (SwGps)	21	3061.1045	145.7669		
Within subjects	72	2283.7046			
Flight condition (F)	1	186.6629	186.6629	6.058	0.0226*
K x F	2	136.5006	68.2503	2.215	0.1330
F x SwGps	21	647.0401	30.8114		
Display location (D)	1	80.6219	80.6219	3.416	0.0787
K x D	2	13.7177	6.8589	0.291	0.7526
D x SwGps	21	495.6785	23.6037		
F x D	1	0.4138	0.4138	0.014	0.9067
K x F x D	2	104.8042	52.4021	1.780	0.1918
F x D x SwGps	21	618.2626	29.4411		

* = significant result.

Table E-7

IFR Flight Heading Deviation (degrees [log])
Means Summary Table

Keyboard type	Display location	Portion of flight	N	Mean	Standard Deviation
Doppler	Keyboard	Before	7	0.220	1.793
Doppler	Keyboard	During	7	2.294	0.985
Doppler	Panel	Before	7	1.158	0.802
Doppler	Panel	During	7	2.526	0.377
Two letters	Keyboard	Before	8	1.221	1.265
Two letters	Keyboard	During	8	2.094	0.848
Two letters	Panel	Before	8	0.025	1.591
Two letters	Panel	During	8	1.941	0.584
Full	Keyboard	Before	8	0.571	1.220
Full	Keyboard	During	8	1.737	0.923
Full	Panel	Before	8	0.669	0.990
Full	Panel	During	8	1.844	0.839

Table E-8

IFR Flight Heading Deviation (degrees [log])
Analysis of Variance Summary Table

Source	df	SS	MS	F	p
Between subjects	22	20.9877			
Keyboard type (K)	2	1.8141	0.9071	0.946	0.4092
Subject with Groups (SwGps)	20	19.1736	0.9587		
Within subjects	69	131.5409			
Display location (D)	1	0.0100	0.0100	0.009	0.9253
K x D	2	6.1039	3.0519	2.759	0.0868
D x SwGps	20	22.1200	1.1060		
Portion (P)	1	46.0970	46.0970	33.033	0.0000*
K x P	2	1.1357	0.5678	0.407	0.6735
P x SwGps	20	27.9098	1.3955		
D x P	1	0.1306	0.1306	0.104	0.7504
K x D x P	2	2.9159	1.4580	1.161	0.3310
D x P x SwGps	20	25.1179	1.2559		

* = significant result.

Table E-9

IFR Flight Airspeed Deviation (knots [log])
Means Summary Table

Keyboard type	Display location	Portion of flight	N	Mean	Standard Deviation
Doppler	Keyboard	Before	8	0.429	1.140
Doppler	Keyboard	During	8	1.043	0.640
Doppler	Panel	Before	8	0.634	1.153
Doppler	Panel	During	8	1.166	0.757
Two letters	Keyboard	Before	8	1.136	1.298
Two letters	Keyboard	During	8	1.190	1.270
Two letters	Panel	Before	8	0.749	1.258
Two letters	Panel	During	8	1.301	0.749
Full	Keyboard	Before	8	1.029	1.415
Full	Keyboard	During	8	1.677	0.834
Full	Panel	Before	8	0.826	0.843
Full	Panel	During	8	1.375	1.191

Table E-10

IFR Flight Airspeed Deviation (knots [log])
Analysis of Variance Summary Table

Source	df	SS	MS	F	p
Between subjects	23	52.3539			
Keyboard type (K)	2	2.7847	1.3923	0.590	0.5665
Subject with Groups (SwGps)	21	49.5692	2.3604		
Within subjects	72	55.2120			
Display location (D)	1	0.1375	0.1375	0.141	0.7107
K x D	2	0.7397	0.3698	0.380	0.6905
D x SwGps	21	20.4220	0.9725		
Portion (P)	1	5.7959	5.7959	8.376	0.0087*
K x P	2	0.4299	0.2149	0.311	0.7382
P x SwGps	21	14.5315	0.6920		
D x P	1	0.0673	0.0673	0.112	0.7412
K x D x P	2	0.4623	0.2312	0.384	0.6878
D x P x SwGps	21	12.6259	0.6012		

* = significant result.

Table E-11

IFR Flight Altitude Deviation (feet [log])
Means Summary Table

Keyboard type	Display location	Portion of flight	N	Mean	Standard Deviation
Doppler	Keyboard	Before	8	0.738	1.375
Doppler	Keyboard	During	8	1.550	0.763
Doppler	Panel	Before	8	1.604	1.014
Doppler	Panel	During	8	2.099	0.689
Two letters	Keyboard	Before	8	1.784	0.804
Two letters	Keyboard	During	8	1.463	1.157
Two letters	Panel	Before	8	1.605	0.875
Two letters	Panel	During	8	1.643	1.073
Full	Keyboard	Before	8	1.838	1.379
Full	Keyboard	During	8	2.060	1.276
Full	Panel	Before	8	2.127	1.146
Full	Panel	During	8	2.085	0.806

Table E-12

IFR Flight Altitude Deviation (feet [log])
Analysis of Variance Summary Table

Source	df	SS	MS	F	p
Between subjects	23	42.3731			
Keyboard type (K)	2	4.9058	2.4529	1.375	0.2727
Subject with Groups (SwGps)	21	37.4673	1.7842		
Within subjects	72	64.5891			
Display location (D)	1	1.9940	1.9940	1.553	0.2264
K x D	2	2.2073	1.1036	0.860	0.4418
D x SwGps	21	26.9638	1.2840		
Portion (P)	1	0.9673	0.9673	1.376	0.2539
K x P	2	2.6702	1.3351	1.899	0.1732
P x SwGps	21	14.7615	0.7029		
D x P	1	0.0332	0.0332	0.048	0.8280
K x D x P	2	0.5660	0.2830	0.412	0.6700
D x P x SwGps	21	14.4258	0.6869		

Table E-13

Low-Level Flight Heading Deviation (root-mean-square [log])
Means Summary Table

Keyboard type	Display location	Portion of flight	N	Mean	Standard Deviation
Doppler	Keyboard	Before	8	3.914	0.485
Doppler	Keyboard	During	8	4.030	0.568
Doppler	Panel	Before	8	4.084	0.531
Doppler	Panel	During	8	4.241	0.422
Two letters	Keyboard	Before	8	4.023	0.370
Two letters	Keyboard	During	8	4.126	0.503
Two letters	Panel	Before	8	4.046	0.380
Two letters	Panel	During	8	4.257	0.449
Full	Keyboard	Before	8	4.277	0.217
Full	Keyboard	During	8	4.225	0.348
Full	Panel	Before	8	4.240	0.254
Full	Panel	During	8	4.324	0.326

Table E-14

Low-Level Flight Heading Deviation (root-mean-square [log])
Analysis of Variance Summary Table

Source	df	SS	MS	F	p
Between subjects	23	10.0099			
Keyboard type (K)	2	0.6977	0.3489	0.787	0.4722
Subject with Groups (SwGps)	21	9.3122	0.4434		
Within subjects	72	6.0976			
Display location (D)	1	0.2379	0.2379	1.392	0.2512
K x D	2	0.1073	0.0536	0.314	0.7358
D x SwGps	21	3.5882	0.1709		
Portion (P)	1	0.2564	0.2564	3.874	0.0624
K x P	2	0.0933	0.0466	0.705	0.5092
P x SwGps	21	1.3899	0.0662		
D x P	1	0.0541	0.0541	3.150	0.0904
K x D x P	2	0.0097	0.0048	0.281	0.7596
D x P x SwGps	21	0.3609	0.0172		